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Air Classification for Reclamation Processing of Solid Wastes[1]

RICHARD A. BOETTCHER

Stanford Research Institute,
Southern California Laboratories,
South Pasadena, Calif.

A laboratory-size zigzag air-classification unit was used to make a preliminary assessment of the economic feasibility of air classification as a method of separating dry fractions of solid wastes. The method was shown to have application for paper salvage and nonferrous-metal recovery from shredded auto-body waste and to be a low-cost process for increasing the marketability of compost. Design requirements for processing solid wastes with a full-scale commercial unit are estimated, and required supplemental equipment (shredders, screens, dryers) is identified.

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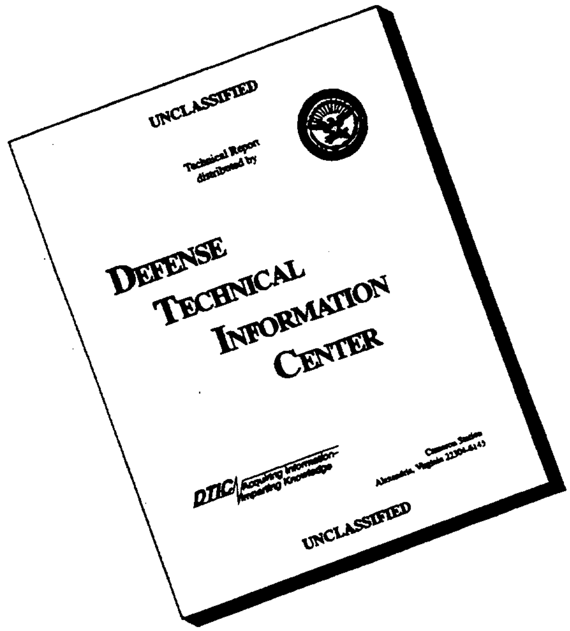

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Air Classification for Reclamation Processing of Solid Wastes

RICHARD A. BOETTCHER

Since enactment of the Solid Waste Disposal Act (PL 89-272) on October 20, 1965, the spotlight of publicity has been thrown on the nation's solid-wastes-management problem. By means of national conferences, symposia, public hearings, and the like, the staff of the federal solid-wastes program is carrying out a dual-purpose, public-information program. One objective of this program is to awaken a lethargic public and its elected representatives. The other is to present the solid-waste challenge to professional engineers and technical managers practicing in the disciplines involved.

Those already in the field know of the rapid increase in the quantities of solid wastes that can be brought about by air-pollution-control legislation that outlaws open burning, the increased quantities of waste generated by populations whose living habits are undergoing changes that accompany increased affluence, and the increases in demolition waste resulting from massive programs of urban renewal, cnetral-city freeway construction, and the replacement of older buildings with modern structures.

Also to be considered, along with the quantitative and qualitative changes in the material being collected, are the changes in collection and salvage methods being brought about by continually increasing labor costs. Combined collections have largely replaced segregated collections, thereby reducing collection costs. On-site compaction of commercial wastes containing large quantities of paper and cardboard is a rapidly growing extension of this trend. In only a few specialized cases, it is now economical to salvage rags, newspapers, and corrugated-cardboard boxes by hand picking such items from combined collections of municipal solid wastes. There is a growing realization of the desirability of reducing the quantity of wastes requiring disposal by reclaiming a portion of the flow for reuse. However, there is also the realization that only processes that are mechanized and operate continuously can be seriously considered. Acceptable processes require a minimum input of labor per ton of refuse to separate material into those portions that are reusable and those that must be discarded. Air classification is such a process. The purpose of this discussion is to acquaint interested engineers with characteristics of the air-classification device and to suggest potential applications for separating mixed solid wastes.

SUMMARY

Preliminary research on air classification, as investigated with the zigzag air-classification unit developed by Stanford Research Institute, has indicated the feasibility of using this method of separation to process several types of solid-waste mixtures. Satisfactory separations require:

1 Suitable feed preparation—An air classification unit alone does not usually constitute a complete solid-waste-processing system. Operations such as shredding, drying, and screening often must be combined with the air classifier to achieve optimum separations.

2 Particles with maximum dimensions no greater than three-quarters the least dimension of the column throat.

3 Particles that flow in a granular fashion when fluidized by air—For fibrous materials, this precludes a shredding method that achieves particle-size reduction but produces detrimental aerodynamic characteristics and an undesirable agglomeration of the components of the refuse.

The need for feed preparation was revealed by work with all three types of waste processed experimentally—wastepaper; aged, stockpile compost; and nonferrous trash from auto-body processing.

With wastepaper, shredding was essential before air classification. Shredding is not practiced at the present time, except to a limited extent in recovery of usable corrugated and high-grade mixed papers from commercial and industrial collections. However, shredding is practiced for municipal wastes being composted and for developmental transfer/bailing, retorting, incineration, and landfill operations. Thus, it would not represent an additional processing step in these methods of refuse handling.

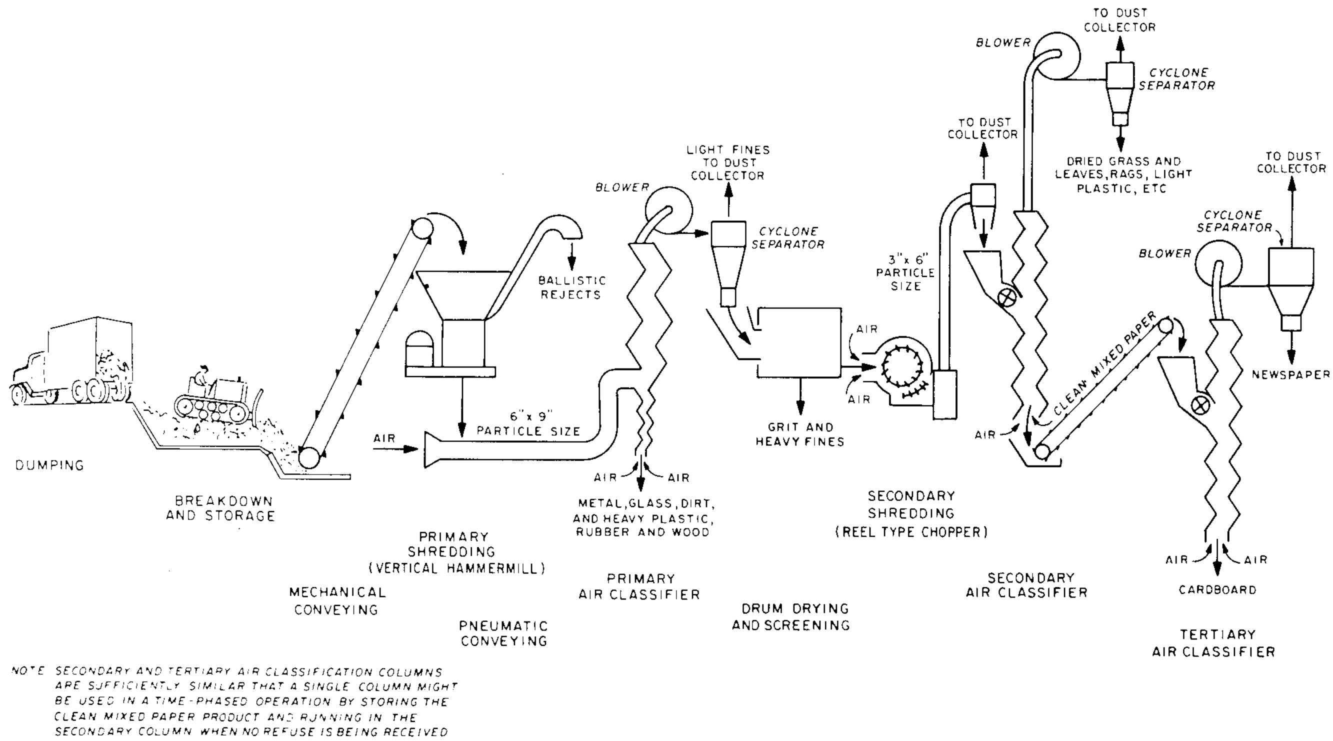

Fig.1 Schematic flow diagram of air-classification process for wastepaper recovery from municipal refuse

Compost that has been aged in outdoor stockpiles requires additional light shredding to break up lumps before it can be air classified to remove impurities, even though it has already been shredded in normal processing. Needed feed preparation for air classification of compost also includes drying and screening, because of the presence of large amounts of fine material that behave aerodynamically the same as low-bulk-density cellulosic components. This is also true for wastepaper.

Nonferrous trash from auto-body processing could be separated effectively without special feed preparation in an air classifier designed to handle quantities available from typical auto-body fragmentizing operations. In certain applications, it probably would be desirable to remove oversize material by screening to reduce the required size and power requirements of the air-classification device. In the experiments performed as part of this research, screening of the auto-body trash was necessary because of the small throat size of the laboratory column.

It is important to note that limitations observed in the operation of the zigzag classification unit on wastepaper are those related to the size of the unit and the characteristics of the materials fed, resulting from the shredding methods used to produce an acceptably small particle size, rather than from limitations of air classification itself as a method of separation. Thus, separating usable wastepaper from municipal refuse appears to be technically feasible in an integrated system employing air classification, even though such feasibility was not conclusively demonstrated in these experiments. A conceptual system is shown schematically in Fig.1. The high capacities, low equipment cost, and low power requirements of such a system, as illustrated by calculations for a compost-processing operation, should make wastepaper salvage by air classification economically feasible as well. Large markets exist for secondary fiber of acceptable quality. Consequently, a significant contribution can be made to conservation of the nation's forest resources by increased recycle of air-classified wastepaper.

LABORATORY UNIT

Zigzag air classification has been pioneered by Stanford Research Institute for processing dry mixtures containing material that can be fluidized and transported in an airstream. Particles of these mixtures are fractionated according to density, size, and aerodynamic properties. Thus, zigzag air classification is somewhat analogous to distillation of hydrocarbon liquids in a petro-

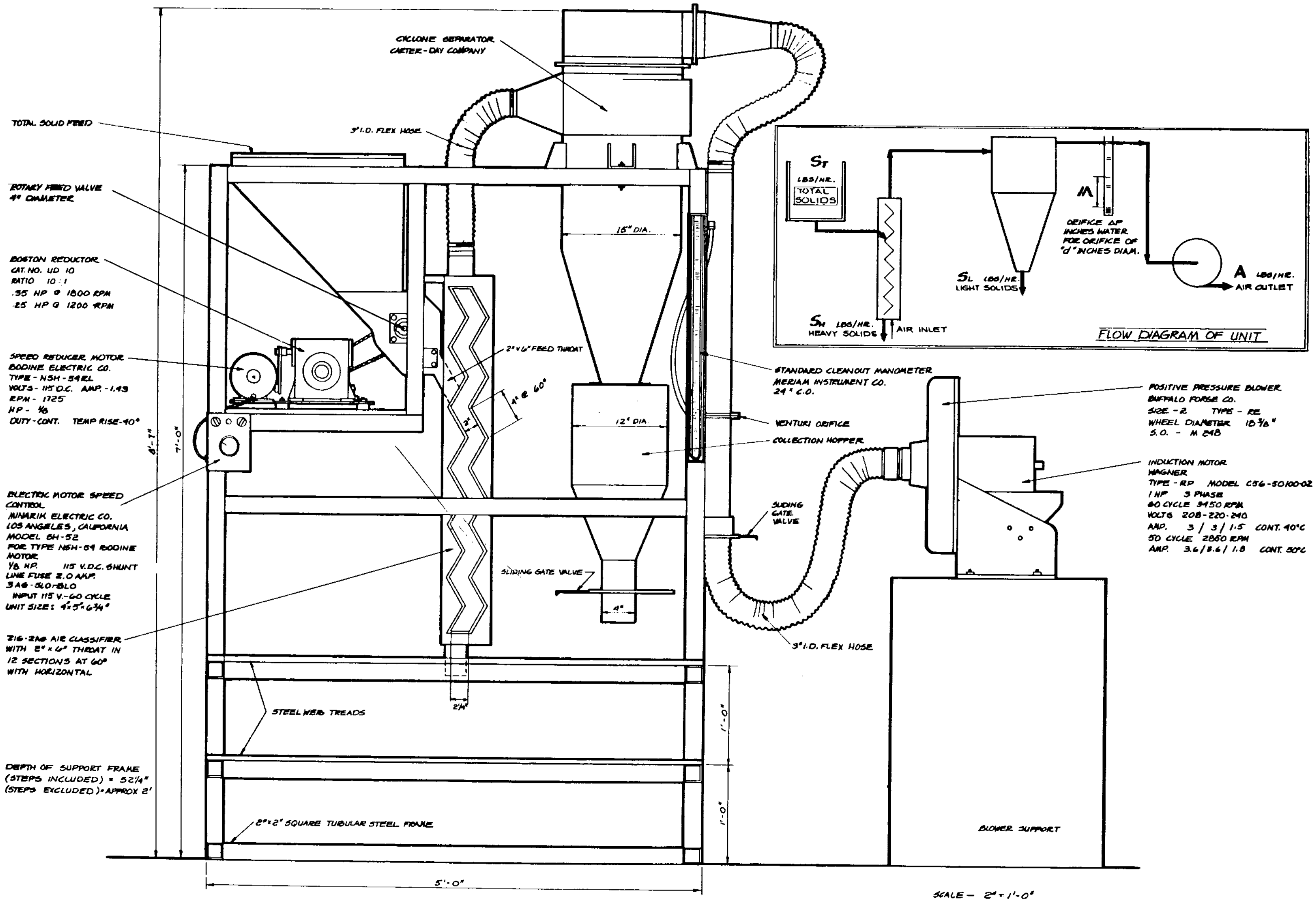

Fig.2 SRI laboratory zigzag air-classification unit

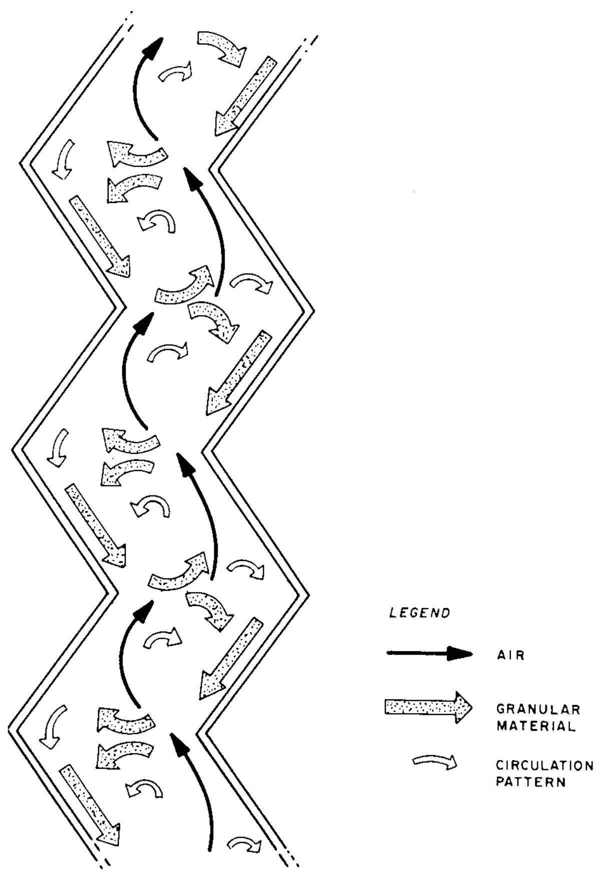

Fig.3 Flow pattern of granular material SRI zigzag air-classification unit

Table 1 Fluidizing Velocities for Selected Pure Components of Waste Mixtures

Component	Velocity (ft/min) 2-Inch Throat Zigzag Classifier	Straight 6-Inch-Diameter Pipe
Plastic wrapping (shirt bags)	Less than 400 (electrostatic)	--
Dry, shredded newspaper (25% moisture)	400-500	350
Dry, cut newspaper		
1-inch rounds	500	350
3-inch squares	--	350
Agglomerates of dry, shredded newspaper and cardboard	600	--
Moist, shredded newspaper (35% moisture)	750	--
Dry, shredded corrugated cardboard	700-750	450-500
Dry, cut corrugated cardboard		
1-inch rounds	980	700
3-inch squares	--	1000
Styrofoam packing material	750-1000 (electrostatic)	--
Foam rubber (½-inch squares)	2200	--
Ground glass, metal, and stone fragments (from auto body trash stream)	2500-3000	--
Solid rubber (½-inch squares)	3500	--

leum-refinery fractionating column. The zigzag principle permits separation of materials with only slightly differing densities whose other properties, such as size, are identical; in almost all cases examined, the zigzag system has proved to be more efficient than any other type of air-classification system.

Fig.2 illustrates the laboratory air-classification unit used in the Institute's basic experiments to develop process data for the suggested applications. It is a 12-stage, zigzag column (fed at the eighth stage from the bottom), through which air is drawn by a high-capacity induction blower. This blower draws air first through the column and then through a conventional cyclone separator that removes material passing upward through the column. Heavy material that cannot be transported in the airstream at any set velocity moves counter-current to the stream and is discharged from the bottom of the column. The separation achieved by the process can be observed through the transparent side walls of the column. The 1-hp induction blower provides superficial velocities up to 3000 fpm for fluidizing material in the 2- by 6-in. throat of the classifier.

When operated to separate a mixture of two uniform granular materials of different aerodynamic characteristics, it is a simple matter to adjust the airflow—as the mixture is fed at a uniform rate into the column—so that conditions of feed rate and airflow are achieved that permit free flow of solid material both up and down the column. Under these conditions, heavy and light materials are separated and re-entrained at each of the steps in the column. The falling material and the upward flowing air, which is transporting the lighter material, provide a combined centrifugal and entrainment action, as shown in Fig.3.

A summary of fluidizing velocities, observed when the laboratory column was operated on selected pure components of municipal-refuse mixtures, is given in Table 1. These data on shredded, fibrous materials show the effects of the size of a particle and the sharpness of its edges on fluidizing velocity. In comparing fluidizing velocities for paper and cardboard in a 6-in. straight pipe with those in the zigzag column, the straight-pipe velocities are approximately one-third lower than those in the column for the same material (dry, shredded newspaper and cardboard and dry, cut newspaper and corrugated-card-

Table 2 Scale-Up Factors Based on Data Obtained with Laboratory Air-Classification Unit

Item	Ratio or Unit	Remarks
Throat area	Throat area of prototype/ throat area of pilot unit	Column capacity scale-up factor
Column width (throat length)	Width of prototype/width of pilot unit	Variable, to give desired column capacity at necessary fluidizing velocity.
Throat width	Throat of prototype/ throat of pilot unit	Variable; widening throat increases column height. Actual prototype throat width determines maximum particle size (oversize) that can be fed.
Column height ratio	Height of prototype/ height of pilot unit	Geometrical scale-up; wider throat requires taller column for same number of flow reversals or "plates." Reduced number of effective "plates" reduces separation efficiency.
Flow ratio	**Cfm of prototype/cfm of pilot unit**	**Numerically the same as throat area ratio, since same superficial velocity must be maintained.**
Pressure drop	**Inches of water**	**For same throat velocity and loading, column pressure drop of prototype is same as for pilot unit. Add approximately 2-in. water for prototype cyclone.**
Power requirement	**Horsepower**	Calculated from prototype blower cfm and pressure drop. Not determined for pilot unit.

board rounds). Shredded and cut newspaper appeared to differ little in fluidizing velocities in either the column or the straight pipe, and there was no observable difference in straight-pipe velocities for large or small cut-paper specimens. On the other hand, cut cardboard required a one-fourth to one-third greater velocity than did the shredded material, and large squares required about 50 percent greater velocity for suspension than did small rounds. This is of considerable significance for separation; whereas there exists a 250 fpm velocity difference between cardboard and newspaper (about 50 percent of the lower fluidizing velocity) when finely shredded, a difference of 650 fpm in velocity exists between large pieces (almost 200 percent of the lower fluidizing velocity) when they are cut to minimize the aerodynamic effect of torn edges. The greater air velocities also would permit greater particle agitation for removal of entrapped fine particles.

It was concluded from bench-scale experiments with the laboratory unit that air classification is technically feasible for processing semifibrous solid-waste materials such as compost and auto-body trash. For light, more fibrous materials such as municipal refuse, the results were favorable but inconclusive. Additional research is necessary to demonstrate a workable

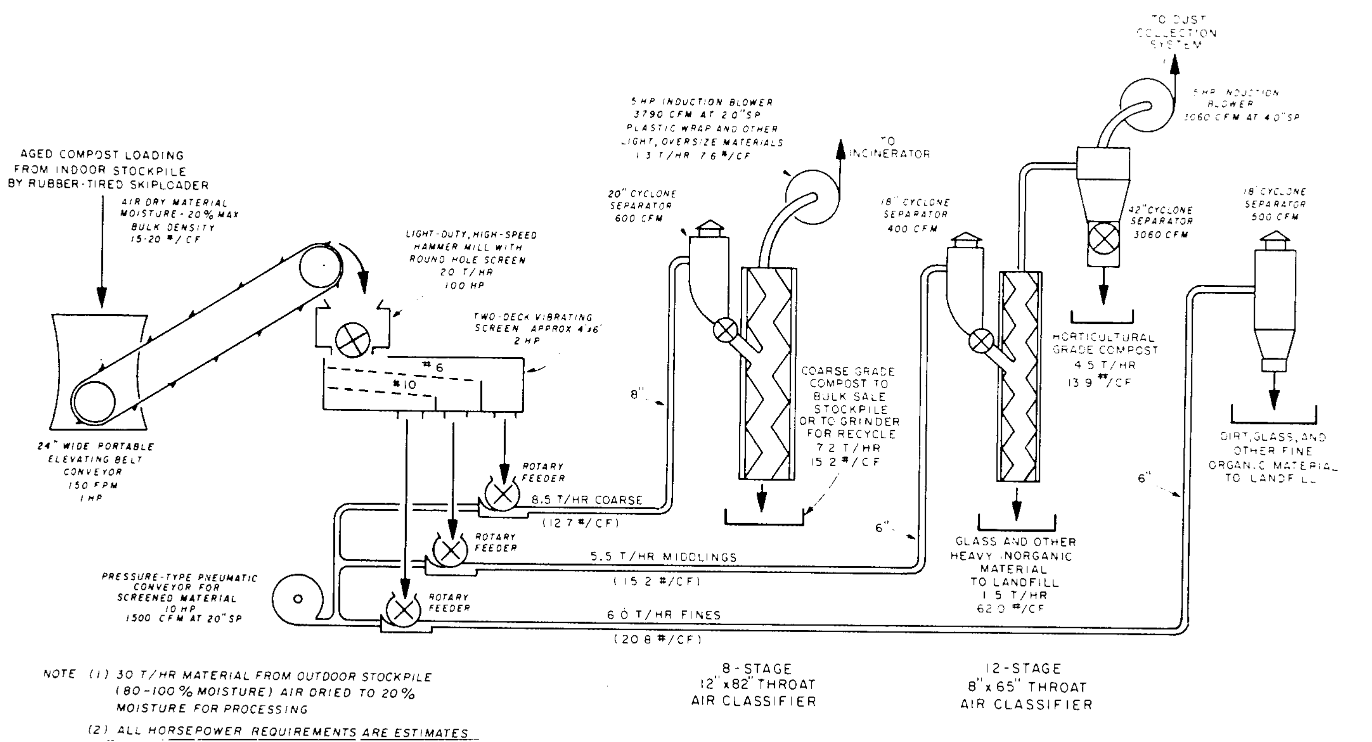

Fig.4 Process flow diagram of air-classification system for production of horticultural-grade compost from aged stockpile material

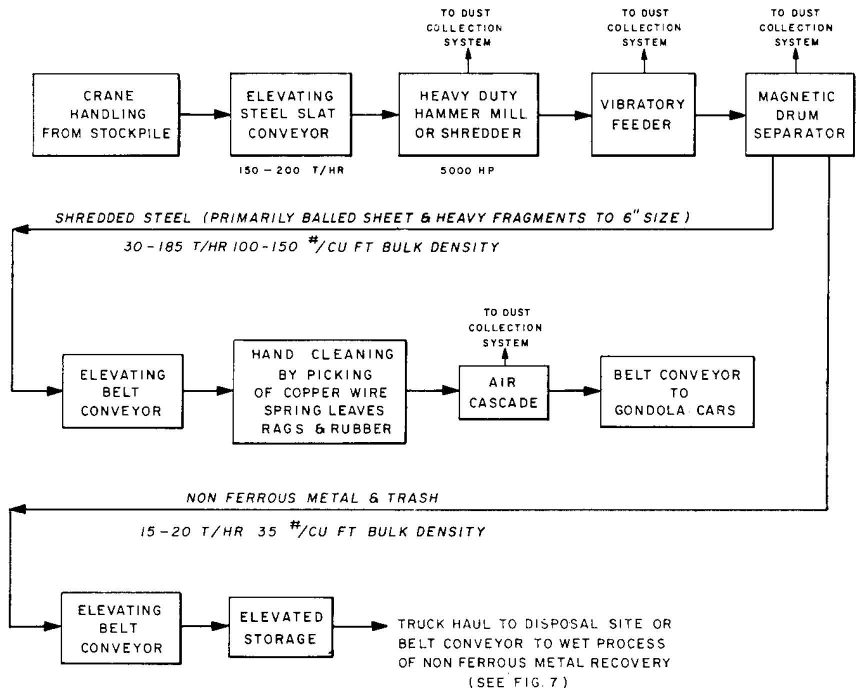

Fig.5 Block flow diagram of conventional auto-body shredding system

process for paper-stock recovery from combined collections of municipal and commercial wastes. This work must include experiments with a larger air-classification column and investigations into the performance of commercially available shredding and screening equipment on high-paper-content feeds. Improvement of commercially available feed-preparation equipment (shredders and screens) may be necessary for use in an air-classification system.

It is possible from laboratory air-classification results to scale up to commercial-size equipment. Scale-up factors are listed in Table 2. However, because of the empirical nature of the relationships among the factors that influence air-classifier operation, it is necessary to establish experimentally those relationships of importance for any desired separation. This involves: 1) determination that the mixture of materials can be processed satisfactorily, and 2) establishment of the degree of separation that is desirable or possible. When a satisfactory separation has been achieved at small scale, it is then possible to expand the operation to the scale at which commercial processing is contemplated.

In the case of compost, both requirements could be satisfied; the material could be handled in the laboratory unit and, by comparison with other acceptable compost materials (such as dried sewage sludge and dairy manure), performance criteria for the quality requirements of commercial separation could be approximated. Thus, it was possible, on the basis of results obtained in this study, to estimate the performance of a full-scale plant for compost processing.

PROCESSING COMPOST FROM MUNICIPAL REFUSE

Two 14-ft air classifiers were selected for a 30-ton/hr compost plant (Fig.4). The classifier for removing plastic and other light material from the coarse screenings before recycling or bulk sale is an eight-stage unit with a throat size 12 by 82 in. The column for separating glass and other heavy contaminants from horticultural-grade compost is 12-stage and has throat size 8 by 65 in. Five-horsepower blowers would be required on each column, but the operating power requirement would normally be less than 7.5 hp for both units. The two columns, complete with blowers and cyclones, would cost approximately $42,500. A complete processing plant would also require equipment for shredding and screening, as well as facilities for in-plant materials handling. Such a plant would handle 30 ton/hr of stockpile compost at 80-100 percent moisture content, after it had been air dried to a maximum moisture content of 20 percent. The actual plant throughput of air-dried compost would be 20 ton/hr. Using the unit's capacity on air-dried material as a base, an estimate of cost

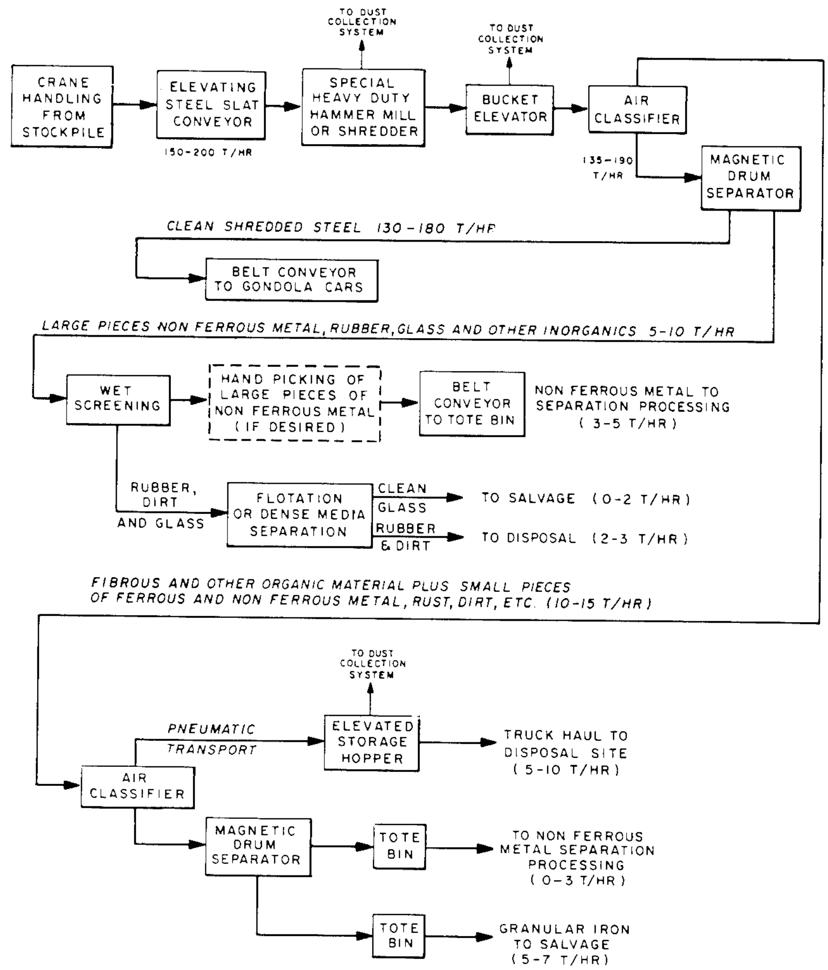

Fig.6 Block flow diagram of modified system for auto-body shredding, including nonferrous-metal recovery

suitable for preliminary comparison with other methods of compost processing indicates that the capital investment in such a plant, excluding land, would approximate \$5000/ton/hr capacity in this size range. Plant operating cost, including depreciation, is estimated to be 50¢/ton (dry basis) for a single-shift operation and 30¢/ton for three-shift operation. Of the latter figure, approximately 20¢/ton is attributable to the cost of shredding.

PROCESSING AUTO-BODY WASTE

In the case of auto-body waste, only one of the conditions required for scale-up was satisfied. The waste could be separated satisfactorily in the small laboratory column, but no information was provided on the beneficiated feedstock requirements for subsequent nonferrous-metal-recovery processing.

Thus, the process for nonferrous-metal recovery from auto-body trash could not be developed to the extent possible for compost. Air-classification runs on auto-body material demonstrated only that close separations could be made; there was no attempt to optimize these separations or to concentrate any particular metallic constituent. However, the results achieved were sufficient to permit comparisons tobe made of conceptual air-classification processing with the process currently being employed for ferrous-metal separation and a proposed process for nonferrous recovery. Process diagrams are given in Figs.5, 6, and 7.

A typical auto-body shredding operation is illustrated in Fig.5. Because of air-pollution regulations, upholstery and other combustibles cannot be removed by burning before shredding. Consequently, magnetic separation leaves this material in the nonferrous stream. Another consequence of not being able to burn is an explosion hazard, the result of dust from shredding and subsequent material-handling operations; this

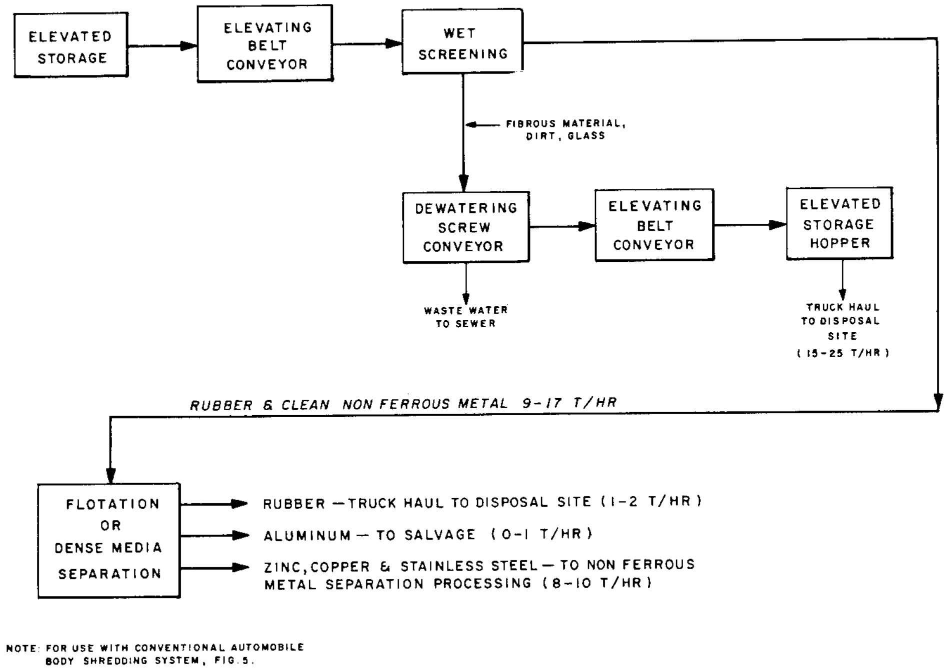

Fig.7 Block flow diagram of wet system of non-ferrous-metal recovery from auto-body trash

dust must be collected to prevent air pollution, as well as to control the explosion hazard.

Fig.6 shows how air classification could improve the conventional separating process. Magnetic separation is still employed; however, its effectiveness is increased by the prior removal of all fibrous material by air classification, which also eliminates hand picking to remove contaminants such as rags, rubber, and copper wire. Air classification also more effectively removes the dust from the ferrous stream than do the air cascades frequently employed for this purpose.

Further advantages of air classification are evident when the processing system is expanded to include the recovery of nonferrous metals. Fig.7 shows a wet process that is under construction for separating rubber, aluminum, zinc, copper, and stainless steel from the trash stream currently disposed of to landfill. Even though approximately 15 ton/hr of material is recovered, the weight of material requiring disposal is not reduced (and disposal costs remain unchanged) because the fibrous material has become water-soaked in the process. When air classification is employed (Fig.6), the wet screening and flotation is done on a smaller stream of material, which reduces the required size of new equipment or increases the capacity of an existing installation. The material for landfill disposal is dry, having been removed by air classification rather than wet screening, and its weight is less by approximately 50 percent.

In summary, advantages of the modified processing system employing air classification are:

1 Improves efficiency of magnetic separations by removal of fibrous material from magnetic separator feed.
2 Eliminates hand picking for final clean-up of steel.
3 Reduces dust content of steel.
4 Reduces cost of dust-collection installation.
5 Reduces amount of material requiring landfill disposal.
6 Permits simple, hand-salvage operation on larger fragments of nonferrous metal, if desired, by separation from fibrous trash.
7 Increases capacity of wet-screening and flotation equipment.

PROCESSING WASTEPAPER

Because of the size limitations of the laboratory air-classification column and the accompanying problems of shredding the refuse to be processed, it was not possible to demonstrate conclusively that the salvage of a usable grade of paper from municipal refuse was technically feasible. Since satisfactory classification could not be effected, the process flow diagram (Fig.1) developed for paper-recovery processing is indicative only of the conditions anticipated for a full-size column and larger-size particles with more sharply cut edges (relative to the size of particle) than were obtained in the laboratory shredder. However, it is believed that a new grade of clean and uniformly shredded paper consisting of mixed newspaper, kraft-paper stock, and corrugated cardboard—with little or no styrofoam packing and sheet plastic and only small percentages of paper or paperboard that is highly filled (such as magazine stock) or that contains waterproofing (such as waxed paper, butter cartons, and the like)—could be produced economically on a commerical scale from combined domestic wastes. Further research is being proposed to establish the feasibility of such reclamation. Such a reclaimed product would have value, and might open up, a new market for secondary fiber in the paper industry.

The recycling of wastes can have important effects on waste-management costs. In the United States, paper currently accounts for about 50 percent, by weight, of municipal solid wastes. Secondary fiber (wastepaper) represents the second largest supply of fibrous raw material, following wood pulp, for the U. S. paper industry. Between 10 percent and 20 percent of this paper is now salvaged and reused according to one source.[2]

Assuming that there is a market for recycled paper, this same source estimates waste-management costs for each level of recycling. In New York City, for instance, where paper not recycled is disposed of along with other solid wastes by incineration, subsequent disposal of the incinerator residue being by sanitary landfill, it is estimated that the annual disposal cost for 20 percent recycle is about one and one-half times the cost for 80 percent recycle, a difference o approximately $100 million annually for the New York region.

Another source[3] estimates that, in 1966, 10 million tons of paper stock (wastepaper) were recycled and became raw material for new products. The U. S. Forest Service predicts the volume will reach 17 million tons by the year 2000. Employment in 1958 to collect this material and get it to market involved 10,000 employees with a payroll of $45 million. Wastepaper provides about 25 percent of the raw material for the paper and paperboard industries. The total value of paper stock (wastepaper to consuming mills) is greater than $300 million per year. A beneficial effect on conservation was the fact that 12,800,000 cords (13 million acres) of trees did not have to be cut in 1966 because of the 10 million tons of wastepaper that were used in place of wood (that is, raw material).

Comparative paper reuse in the United States and foreign countries for which data are available is estimated to be:

1 United States, 10 percent (minimum estimate) and 25 percent (maximum estimate).
2 United Kingdom, 27 percent
3 West Germany, 33 percent
4 Japan, 46 percent

New markets are probably essential for a new recycled paper product because of the quantities involved. The city of Los Angeles, excluding the smaller cities of the metropolitan area and commercial collectors in the unincorporated areas of Los Angeles County, picks up approximately 5000 tons of domestic waste daily. During the 1970's, a number of municipal transfer stations will become justified on the basis of transportation economics alone; the minimum size of a transfer station will be 300 ton/day. Los Angeles basin cities, such as Santa Monica and Beverly Hills, have been operating refuse-transfer stations for a number of years. In Orange County, two transfer stations have operated since 1964, and each now processes over 500 ton/day. A third transfer station recently has been completed. Future expansion of these stations to a capacity of 800-1000 ton/day is possible. Thus, considering only facilities already in operation or contemplated in the greater Los Angeles area, a minimum of 3000 ton/day of refuse will probably be handled through municipally built transfer facilities by 1975. If salvage contractors were to operate these stations under no-cost contracts and process the refuse to recover only 25 percent of the incoming material as mixed paper, an assured supply of 750 ton/day would result. At a price of only $5.00 per ton, the dollar value of the recovered paper would be over $1 million per year. In addition, Los Angeles and Orange counties and their municipalities would save the

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[2] New York Regional Plan Association, Waste Management Bulletin No. 107, prepared with the assistance of Resources for the Future, Inc., and the Franklin Institute.

[3] University of California, Sanitary Engineering Research Laboratory, Comprehensive Studies of Solid Wastes Management: Abstracts and Excerpts from the Literature, SERL Report No. 68-3, Berkeley, Calif., June 1968, p. 236.

present cost of transfer-station operation, haul costs would be reduced 25 percent, and landfill life would be extended.

RELATED APPLICATIONS

The ease with which noncombustible material can be removed from municipal refuse has been demonstrated in the laboratory. Air classification is being incorporated in the process flow diagrams of the 400-ton/day combustion power unit (CPU-400) now under development. This unit will produce electrical power in a gas turbogenerator from solid waste that has been gasified by combustion or pyrolysis in high-pressure, fluidized-bed retorts.

When refuse is already shredded, as for composting or fluidized-bed combustion, glass, dirt, rubber, metallics, and wood and heavy plastics (which typically represent 20-25 percent by weight of municipal refuse) can be removed for less than 10¢ per ton by air classification. This opens up many possibilities for recovering usable materials such as ferrous metal and glass. It is known that secondary materials processors are keenly aware of, and are interested in, all developments related to new salvage opportunities. The Sanitary Engineering Research Laboratory of the University of California at Berkeley is interested in salvage as a facet of solid-wastes management.[4]

One further application that appears to merit investigation by those researchers working with refuse incineration is the removal of heavy materials from the incinerator feed by shredding and air classification. Besides the salvage possibilities that would be created, incinerator operation and maintenance costs might be reduced by such removal. New methods of combustion, such as fluidized-bed and grateless systems employing injection of shredded material by blowers or ram-type packers, become worthy of consideration. In conventional incineration, the recovery of materials from the ashed residue by air classification, while not yet investigated by the Institute or others, appears to offer some promise for economical recovery and reuse of secondary materials.

CONCLUSIONS

Separation of heavy materials from dry, shredded, municipal, and commercial refuse can be accomplished easily. It is possible to insert an air-classification column into a vertical run of pneumatic-conveyor piping handling the output of a refuse shredder and to remove metal, glass, rocks, rubber, and wood from the shredded refuse. The cost is estimated to be less than 10¢ per ton, including the cost of pneumatic conveying. Such a separation should be highly desirable in refuse composting, refuse retorting, and for certain experimental types of refuse incineration. It has been adopted as part of the flow diagram of the CPU-400 (combustion power unit) system of refuse gasification.

Conceptually, air classification can provide a number of benefits in the processing of shredded auto-body material, including: 1) improved cleanliness and reduced nonferrous contamination of the steel scrap; 2) reduced quantities (and cost) of waste requiring landfill disposal; and 3) increased capacity of nonferrous-recovery processing facilities.

Compost can be cleaned of glass and other contaminants that reduce its marketability. Yields of over 50 percent combined bulk and horticultural-grade material can be produced by an air-classification process developed by laboratory-column operation. In a 30-ton/hr plant, the cost is estimated to be 30¢ per ton of material processed (24-hr operation), including amortization.

Other findings of importance include the following:

1 The laboratory air classifier is a useful tool for empirical design.

2 For a particular type of refuse and a particular reclamation objective, final system design requires that separations be optimized by a more extensive series of experiments than was performed herein.

3 Empirical determination of design criteria for full-scale air-classification systems, especially for wastepaper, requires an experimental column larger than the laboratory unit used for the reported experiments.

4 The characteristics of material shredded by commercially available shredders must be determined as part of the experimental work on any particular type of refuse requiring shredding.

5 Commercial interest might be stimulated by the construction of a demonstration plant for salvage of paper or other secondary raw materials from refuse.

6 Nonferrous metal recovery from auto body trash is particularly attractive commercially.

[4] University of California, Sanitary Engineering Research Laboratory, Comprehensive Studies of Solid Wastes Management, prepared by C. G. Colueke and P. H. McGauhey, SERL Report No. 67-7, Berkeley, Calif., May 1967, pp. 105-117.

7 Recovery and reuse of glass could stimulate a greater use of nonreturnable glass bottles by the beverage industry.

As a unit operation, the advantage of air classification include:

1 Dry processing capability
2 Sharp, clean, separation capability
3 High-capacity throughput
4 Low power requirement
5 Low operating manpower requirement
6 Dust-free operation.

Air classification is subject to certain limitations, the most significant of which are:

1 Feeder and column throat size impose particle-size limitations for low-capacity systems
2 Multiple-column or repetitive operation is required for more than two-component separations
3 Oversize, semifibrous materials require shredding before classification.